Final Technical Report 2015-2019
Mid-America Integrated Seismic Network -- CERI

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1. Abstract

This report describes the current state, operations, and future directions of the CERI operated portion of the Mid-America Integrated Seismic Network. The Mid-America region of the Advanced National Seismic System is the largest ANSS region in the contiguous United States and includes the locations of the significant 1811-1812 New Madrid and the 1886 Charleston, South Carolina, earthquakes.

Regional monitoring has unfortunately been reduced to just two funded partners: The Center for Earthquake Research and Information (CERI) at the University of Memphis, and the University of South Carolina at Columbia (USC). The region encompasses five ANSS urban monitoring targets (Memphis, St. Louis, Evansville, Charleston, and the Knoxville/Chattanooga corridor) shown in Figure 1 though the reduction in RSNs leaves St. Louis and Evansville without a vested RSN. Areas of elevated hazard (10% probability of exceeding 8% g in 50 years) as defined by ANSS performance standards include the general areas of the New Madrid, East Tennessee and Wabash Valley Seismic Zones, and South Carolina.

The regional seismic networks in the Mid-America Integrated Seismic Network (MAISN) provide raw and derived earthquake products to the ANSS system and provide local expertise on earthquake information, models, and methods. Each institution provides core operations and maintenance as well as locally specific tasks and expertise where appropriate. The purpose of the MAISN is twofold:

1. to provide scientists, engineers, public and private entities, emergency responders, and the media with rapid and reliable information about felt and damaging earthquakes within a timeframe that maximizes the utility of the information,
2. and to provide high quality data on a timely basis to the scientific and engineering communities for the purpose of improving:
   - seismic hazard estimation for urban population centers and the lifelines and critical facilities upon which they depend
   - estimation and measurement of strong ground motions, our understanding of the basic earthquake process, and seismotectonics of earthquake zones, particularly in intraplate regions.

The CERI seismic network consists of 132 permanent seismic stations (NM, ET, and, under contract with Arkansas Geological Survey, AG network codes) and 233 stations are imported from other networks for a total of about 1,500 data channels processed in real-time. Automatic solutions produced by the real-time systems of our ANSS Quake Monitoring System (AQMS) are manually reviewed within about 2-5 minutes prior to posting to the Product Distribution Layer (PDL). Products include online catalogs, archived waveforms, rapid notifications and maps of recent earthquakes. About 400 earthquakes per year are processed in the NM region and 110 in the SE region though induced seismicity swarms may swell those rates to more than 1000/year. Earthquake risk is the potential impact on society of earthquake hazard, and FEMA estimates the Annualized Earthquake Loss for the Central U.S. is \$0.38B and for the Southeast U.S. is \$0.16B (FEMA 366, 2008).

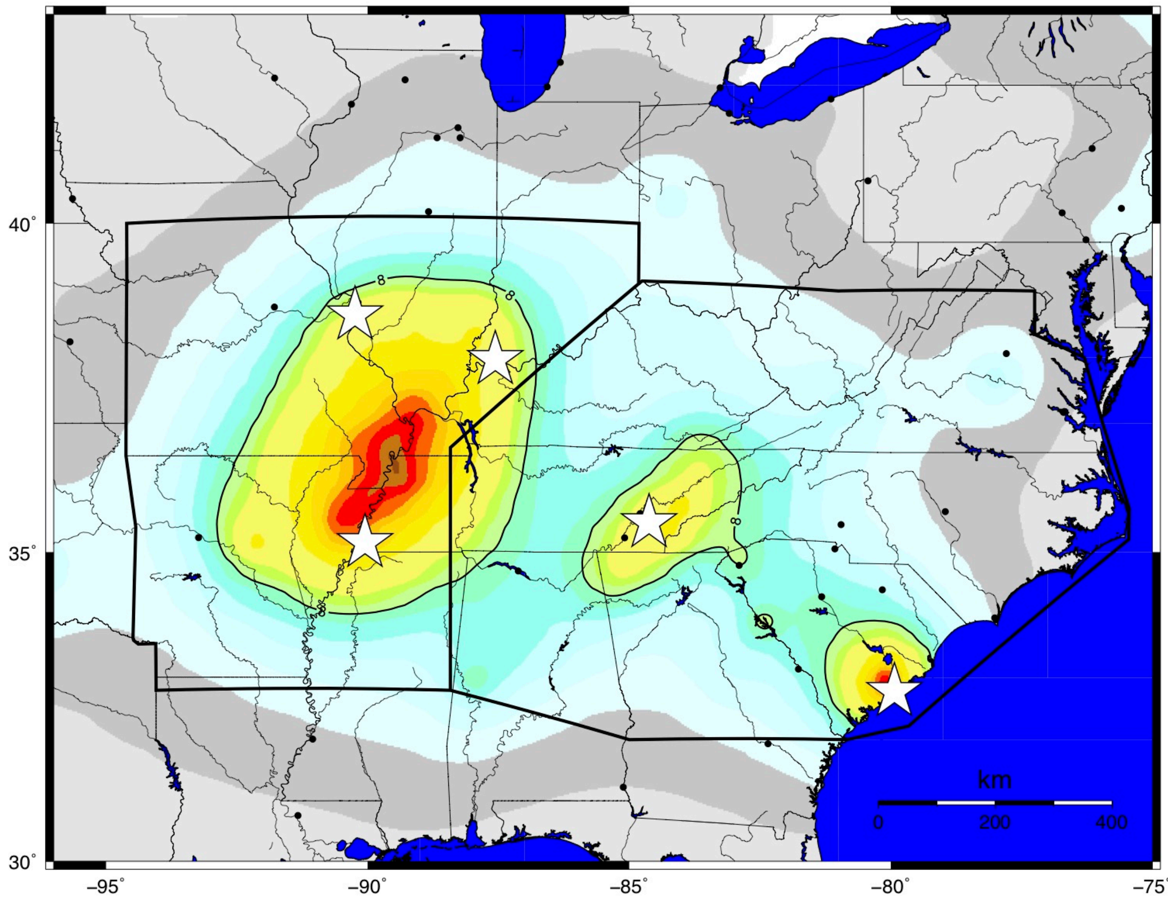

Figure 1. 2018 National Hazard Map. PGA B/C Boundary, 10% probability of exceedance in 50 years for the NM and SE authoritative regions (gray polygons). Stars are urban monitoring targets from USGS Circular 1188 and black dots are Nuclear Power plants. The 8%g exceedance level is the line contour.

2. Network Description

The CERI seismic network consists of 132 permanent seismic stations (26 broadband, 18 free field strongmotion, 12 digital shortperiod with collocated strongmotion, and 76 shortperiod 3-component nine of which are slated for conversion to digital using previously obtained funding). Telemetry concerns require operation of twelve data concentrators (or nodes) linked to a central processing facility at CERI (Figures 2 and 3). Each node contains about 11 days of continuous revolving buffer and local creation and storage of triggered datasets. All nodes are linked to CERI in continuous near-real-time. The remote nodes are able to operate autonomously in the event of communication failure and thus, in addition to helping solve the *last-mile* communication problem, provide a backup for the regional processing in Memphis.

CERI maintains a microwave communications backbone (red line figure 2) to provide private TCP/IP communications between the central processing at CERI and the remote New Madrid Seismic Zone (NMSZ) nodes. To mitigate against fades during inclement weather (and avoid single points of failure), DSL or other ISP internet is available at each node.

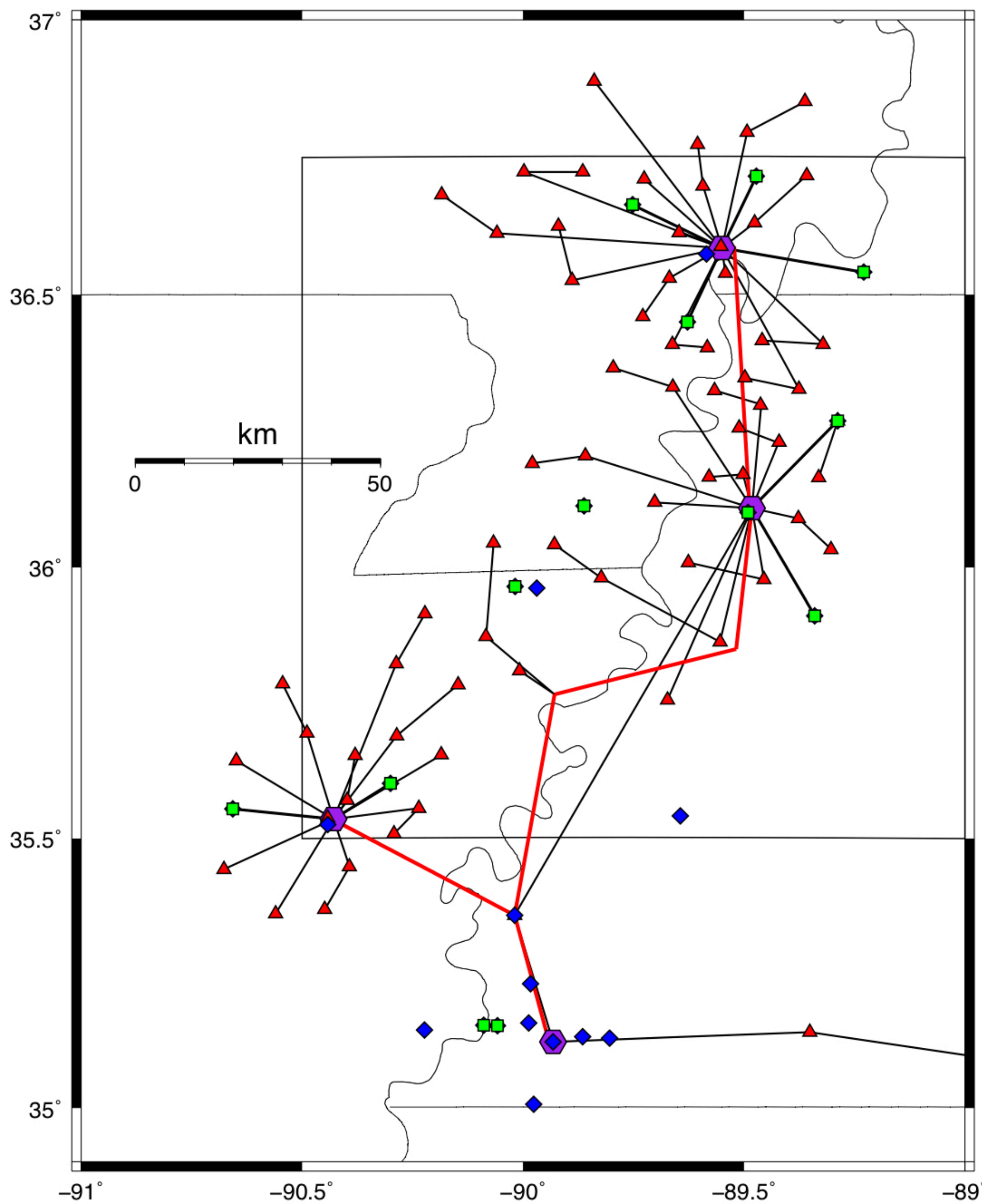

Figure 2. NMSZ stations operated by CERI with telemetry topology. Red triangles are shortperiod stations, green squares are broadband, and blue diamonds are strongmotion. Black lines are digital or analog radio. Red lines are the 2.4 GHz spread spectrum digital backbone that provides TCP/IP connectivity with the nodes (purple hexagons). Black box is rectangle referred to in section 3.B.1.a.

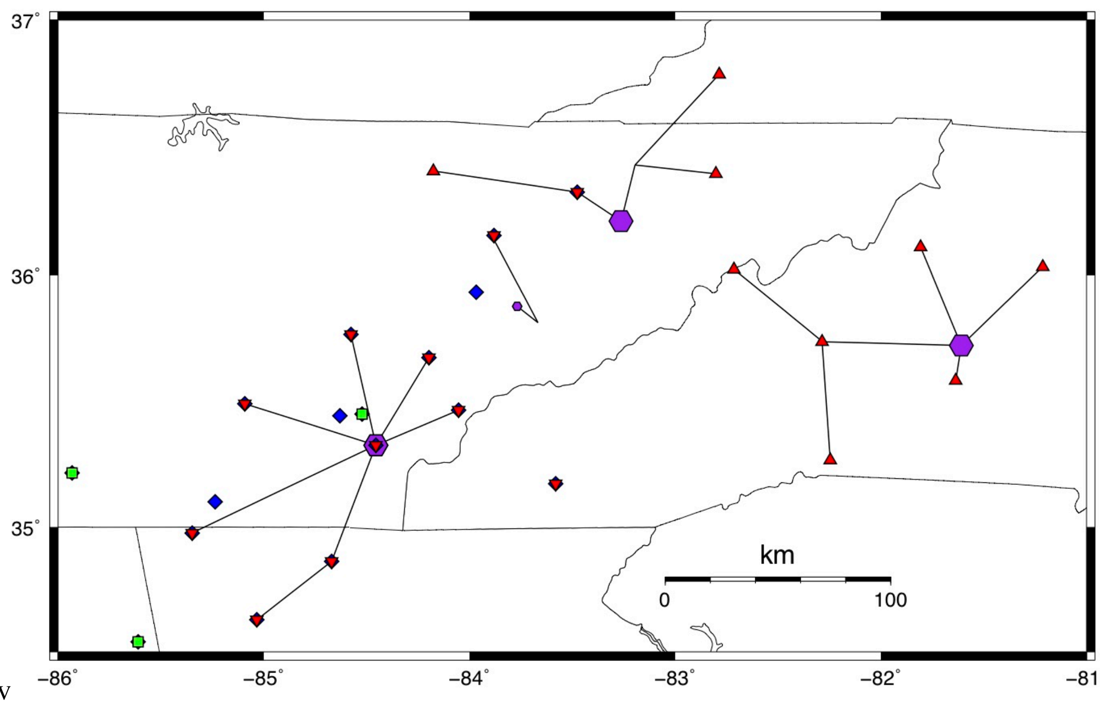

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Figure 3. ETSZ stations operated by CERI with telemetry topology. Red triangles are shortperiod stations, inverted triangles are digital, green squares are broadband, and blue diamonds are strongmotion. Black lines are digital or analog radio. Node connectivity is accomplished via public internet or DSL.

Subnetwork triggers are analyzed daily at CERI for both the NMSZ and East Tennessee Seismic Zone (ETSZ). Digital *helicorder* records are monitored for state of health purposes and missed events (paper *helicorders* were deprecated in 2008). Routine event locations are submitted to ComCat via PDL and posted on social media (twitter and Facebook). Reviewed parameters are similarly shared and are emailed to the ENS listserv. By far our most popular tool is the REQ webpages accounting for the bulk of the web traffic over the past twelve months. Events older than the 6 month buffer in REQ are available in our online catalog. Pseudo-helicorder images provide a quick review of station operation and events for the previous week. All channels are made available for archiving continuously at the IRIS DMC using the IRIS *ringserver* software.

Dual AQMS real-time systems are in production and produce alarms for events above about magnitude 1.8 anywhere in both NM and SE authoritative polygons (gray polygons in Figure 1) using all ANSS stations in the region. Alarms are emailed to analysis staff for all events and sent to their cell phones for events greater than 2. The AQMS Duty Review Page provides the ability to “accept” an event, which triggers alarms that submit the event to ComCat via PDL.

We are in the process of migrating AQMS from sparc Solaris/oracle to Linux/postgres. Hardware is live and racked and we have a contract with ISTI for assistance. A site visit by ISTI is planned for early 2020 and we expect the new systems to be in production by the end of the year.

Seismicity rates in the central and southeast U.S. do not support use of a rotating duty seismologist. Instead the full-time analyst and PI are on call 24/7. A CERI seismologist (usually Steve Horton) is able to fill in if both the analyst and PI are unavailable.

3. Operations and Standards

A. Implementation of Policies, Standards, and Procedures

ANSS policies, standards, and procedures are primarily summarized in the five documents approved by the NIC in May 2014 and updated in 2019, that include Instrumentation Standards, Implementation Standards, and Performance Standards.

1. Instrumentation Standards

All broadband and strongmotion stations in the NM and ET networks conform to ANSS instrumentation standards for regional seismic networks. We also operate a significant number of shortperiod stations that remain critical to meeting other performance standards.

a. The case for shortperiod stations

Dunn et al. (2010) conducted a high-resolution relocation of hypocenters from the active part of the NMSZ and found that, "*The close correspondence of the hypoDD relocations and the original catalog locations demonstrate the high quality of the permanent network data set. Continued recording of microseismicity by the network over time will allow better constraints to be placed on seismogenic structures associated with the major arms of seismicity*." To estimate the contribution of the analog shortperiod stations, we examine earthquakes in the first five months of 2019 within the rectangle 35.5, 36.75 latitude and -90.5, -89.0 longitude (rectangle shown on Figure 2). There are 128 events in the catalog that meet the search parameters. Of those, 71 have at least 5 arrivals from broadband or strongmotion stations. We relocated those stations with Hypoinverse with the same configuration as we use with AQMS. Errors detailed in table 2 suggest the variability in the quality of the solutions is much greater without the shortperiod stations leading to a much larger difference between the mean and median of the error parameters of the broadband only solutions. Also, the number of arrivals is increased by a factor of 4 or more and the gap is decreased by about a factor of 3. The minimum distance only increases from 5 to 9 km and the rms is essentially unchanged. The maximum principal error is improved by a factor of 2 to 3 while improvement in the other two directions is minimal. There is a factor of 2 improvement in the depth errors. The columns include npick, the number of arrivals used in the solution; dmin, the distance in km to the closest station; rms is the root mean square of the arrival errors; er1len is the length of the longest axis in the error ellipsoid; er2len is the length of the middle axis, and er3len is the length of the shortest axis; she is the horizontal error in km, and shz is the vertical error.

Table 1. Comparison of errors between catalog locations and locations without the NMSZ shortperiod analog network.

BB Only Arcs	npick	gap (deg)	dmin (km)	rms (sec)	er1len (km)	er2len (km)	er3len (km)	she (km)	shz (km)
Average	10	150	9	0.05	2.58	0.61	0.29	1.64	1.62
Median	6	141	9	0.04	1.33	0.51	0.26	0.53	1.15
With SP									
Average	41	63	5	0.08	0.66	0.36	0.24	0.39	0.6
Median	35	59	5	0.06	0.6	0.37	0.24	0.34	0.56

There are significant technical and resource issues to resolve in order to make progress converting these stations, not the least of which is avoiding intermodulation at the central receive nodes. There will be a meeting at ASL in the fall of 2019 to discuss solutions and develop plans for addressing this issue.

b. ET digital shortperiod and telemetry issues

We are currently in a push to convert the entire ET network from analog to digital. Considerable assistance in this effort is provided by Choctaw Telecom. They purchased Geobit digitizers for the remaining analog stations and perhaps more importantly are providing licensed spectrum in the AMTS band (216-220MHz). Many of the remaining ET analog stations do not have line of sight eliminating traditional cell and higher frequency spread spectrum viable solutions. The path problem is solved with the AMTS band though the hardware required is not without idiosyncrasies. While not broadband, this network of digital shortperiod 3-c S-13 stations provide high quality seismograms for local and regional earthquakes. This is illustrated with example seismograms and spectra from an M6.8 earthquake in Northern California, shown in Figure 4. Data recorded at broadband station CPCT (Trillium 120P/Reftek RT130) and shortperiod station DYTN (3-c S-13/Reftek RT130) along with their spectra can be compared in this figure (the Reftek's are also scheduled to be replaced by the end of the current cooperative agreement using USGS Deferred Maintenance supplements).

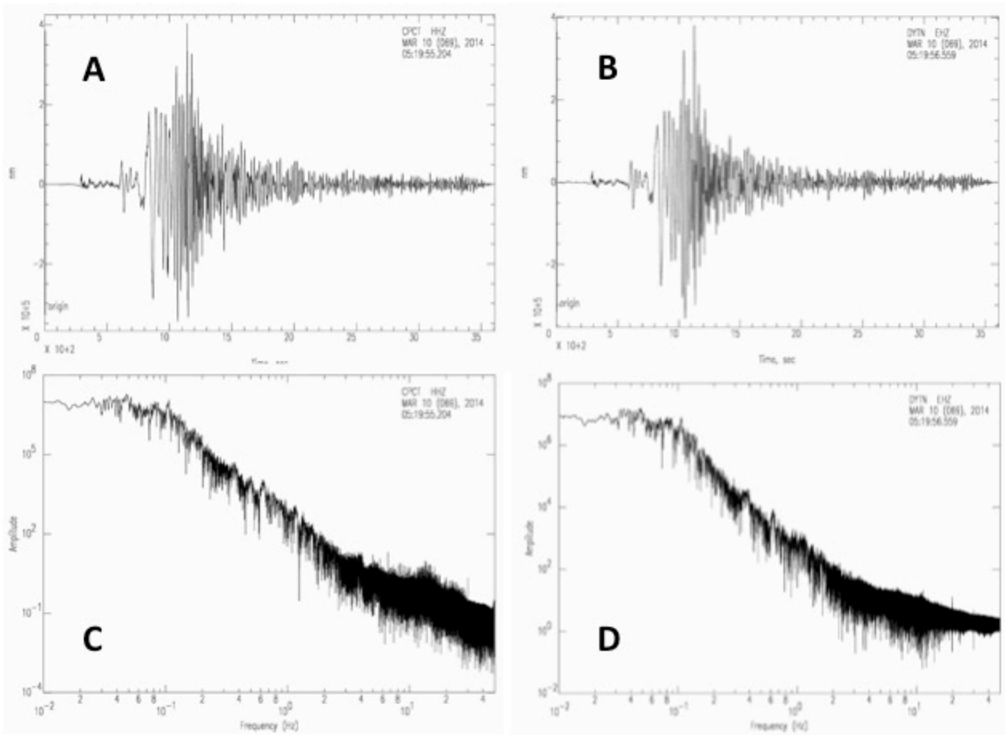

Figure 4. Seismograms and spectra for an M6.8 earthquake near Ferndale, CA on March 10, 2014 recorded at broadband station CPCT (A) and shortperiod digital station DYTN (B). Spectra for the CPCT data (C) and DYTN (D).

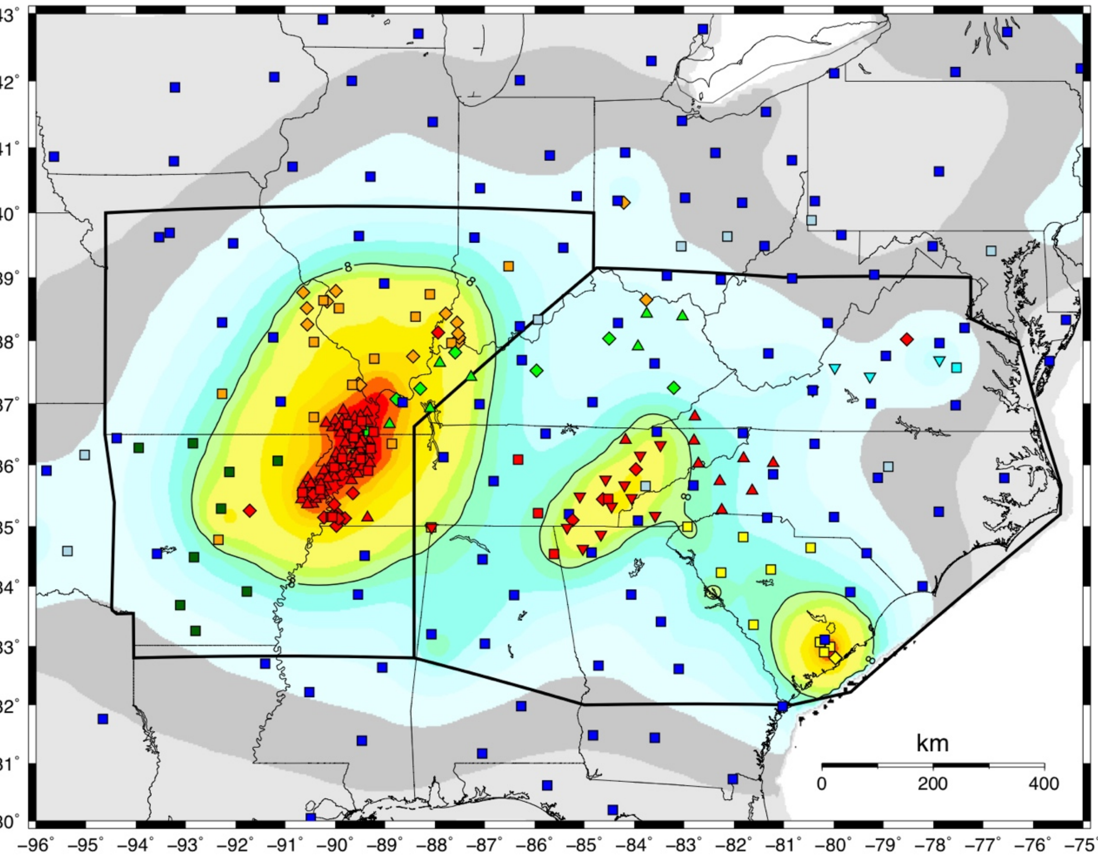

Figure 5. Station Map. Broadband are squares, strongmotion are diamonds, shortperiod analog are triangles, and shortperiod digital are inverted triangles. Red is CERI, orange is SLU, green is UKY, cyan is VPI, yellow is USC, blue is USGS, and light blue is other contributor (e.g. TX, OH, SS, etc.). The underlay is the 2018 PGA B/C Boundary 10% probability of exceedance with the 8%g level contoured. The NM and SE authoritative polygons are outlined with the thick black polygon.

2. Implementation Standards

a. Station Inventory and Metadata

Metadata for all CERI operated stations (AG, NM, and ET network codes) are maintained in SIS. Updates are performed within 3 business days though usually on the same day. Metadata are automatically uploaded from SIS to the IRIS MDA.

b. Distribution of Earthquake Products

We currently use PDL to submit earthquake parametric data in quakeml format to the ANSS ComCat. Past notable exceptions to the normally very accurate automated solutions led us to decide to submit no solutions to PDL without human review. Rapid review is performed using the AQMS Duty Review Page (DRP). If the event location and magnitude are reasonable, the “accept” button on the DRP is linked directly to PDL so reviewed automatic solutions are submitted within 2 to 5 minutes of the event origin time. The reprocessed solution is then updated in PDL within about 15 to 20 minutes. Automated solutions with magnitude greater than 2.0 are sent to staff cell phones for rapid review. Automated solutions with magnitude less than 2.0 are only sent to email so may not be reviewed and processed until the following morning.

We also store event data locally (waveforms and parametric data) that are available on request. CERI maintains an online searchable catalog that is updated automatically via AQMS alarms.

c. ShakeMap

CERI installed and configured ShakeMap in 2005 (Brackman, 2006) but subsequently decided to outsource this function. In order to reliably and robustly operate a complex and highly visible program like ShakeMap, it is essential that an organization frequently test and exercise the system. The rate of earthquakes in the NM and SE regions that produce reasonable opportunities to produce a ShakeMap are insufficient to instill confidence that the system will perform adequately after a damaging earthquake. For this reason, we have agreed with NEIC that NEIC will produce ShakeMaps for the NM and SE regions.

d. Real-time Distribution and Archiving of Waveform Data

We use earthworm exports to export requested data channels to monitoring partners in real-time. Recipients include NEIC, St Louis Univ., University of South Carolina, Virginia Tech, and the Oklahoma Geological Survey.

We use ew2ringserver and ringserver to provide seedlink ports for real-time archiving at the IRIS DMC. The USGS National Strong Motion Program (NSMP) also has access to the strongmotion ports for ringserver.

e. IT Security

CERI seismic networks IT personnel are signatories to the previous USGS Interconnection Security Agreement and anticipate endorsing its replacement.

Login accounts on all seismic network computing systems are extremely limited and generally include only IT and in some cases analysis staff. All connections are encrypted (e.g. ssh). TCP wrappers are employed to restrict domains with access and AQMS systems also use ipfilters to prevent unauthorized non/tcp connections (e.g. oracle).

CERI underwent a detailed University IT Security Audit in late 2017 and addressed all identified weaknesses in the following six months. We continue to work closely with University IT to remain in compliance that includes routine port scans.

f. Continuity of Operations Plan

The CERI Seismic Networks Continuity of Operations plan was written (based in large part on the plan developed by the University of Utah Seismograph Stations) and adopted in October, 2010 and updated in June 2016.

g. Post-Earthquake Reporting

The four basic elements of the CERI Rapid Response Plan are:

1. Verification and Notification – Verify that an earthquake has happened and initiate notification.
2. Field Studies – Coordinate and conduct appropriate field studies following an earthquake
3. Information Response – Coordinate the media/public interaction from CERI.
4. Assessment – Evaluate CERI's response following significant earthquakes.

h. Websites

The CERI seismic networks website (http://www.memphis.edu/ceri/seismic/) provides computed hypocenters and magnitudes, maps and lists of stations used in routine monitoring, links to products and services, and links to monitoring partners as required by the ANSS Implementation standards.

3. Performance Standards

a. Seismic Monitoring/Strong Earthquake Shaking

With the addition of the N4 network, we are able to meet performance standards for the moderate to high hazard areas (8%g contour in Figure 5). Without N4 we are not able to meet these performance targets outside the dense part of the Regional Networks. As explained in section 3.B.1.a above, errors for events below the Mississippi Embayment sediments require a very high station density presently accomplished with the shortperiod network. Without these stations hypocenter uncertainty targets are difficult to achieve except when events are large enough to estimate Moment Tensors (about magnitude 3 or so).

All broadband stations operated by CERI (green squares on Figures 2 and 3, and red squares on Figure 5) have collocated strongmotion sensors. These combined with the free-field strongmotion stations provide the capability for on-scale recording of strong ground motion.

b. Real-Time/Automated Product Generation

Automated earthquake locations are produced within about 2-3 minutes of origin time. We do not post automatic solutions to PDL. While normally very accurate, blasts and deep South American subduction events are difficult to correctly identify automatically and so we require human review of all events.

c. Preparation of Seismologist-Reviewed Products for Significant Earthquakes

For events that are well located with reasonable automatically generated magnitudes, we are able to use the AQMS Duty Review Page to post hypocenter and magnitude within about 5 minutes of origin time. Events are then re-timed by the analyst and updated within about 20 minutes.

We do not produce COSMOS V0-V3 products directly. Instead, we provide seedlink access to strongmotion channels for NSMP.

d. Data Exchange between ANSS Networks

Data export timeliness is primarily limited by packet size. Other latencies within the network are relatively small. Packet lengths are generally 10 seconds or less depending on compression. This is well within the ANSS performance standards.

e. Data Archiving and Public Distribution

Waveform data are sent to the IRIS DMC in real-time where they are made immediately available to external users. Likewise, quakeml format parametric data are sent to PDL and to the CERI online catalog immediately.

CERI has about 7500 events archived for NM since 1995 and about 1600 for ET since 1998. These events include waveforms, hypocenters, and arrival times. All parametric data for these events is in AQMS and ComCat. Only hypocenters for NM events prior to 1995 are loaded.

Metadata are currently maintained in SIS. We usually update changes within about a day and make these data available as described in section 3.B.2.c.

B. Delivery, Availability, and Exchange of Data and Products

As mentioned in previous sections, continuous waveform data are available in the IRIS DMC for all channels in real-time. We also use earthworm export_scnl or ringserver to send 33 channels to neighboring RSNs in real-time. We also export 108 channels to NEIC via a version of export_scnl modified by Dave Ketchum to behave as a ringserver. Epicenters are submitted to PDL within 5 minutes for events recorded well enough to produce reliable automatic solutions and within a few hours for smaller events (e.g. less than magnitude 2.5). Data are imported in real-time for the 364 stations shown in Figure 5 and are fully integrated into AQMS.

We archive event-based waveforms with daily backups to an archive physically located in a different building than the primary archive. These data, while not on the public internet, are available to anyone on request. After AQMS stabilizes, we will upload those data to the archdb and then download to USGS ComCat and the IRIS DMC. The data to be downloaded include parametric data and arrival times.

Earthquake epicenters are available on two CERI websites:

- Recent earthquakes (REQ) of the previous 6-months of hypocenters, http://folkworm.ceri.memphis.edu/REQ/html/index.html
- Searchable online catalog for 1974 to present http://folkworm.ceri.memphis.edu/catalogs/html/cat_nm.html

The online digital helicorder pages (http://www.memphis.edu/ceri/seismic/heli/) generate a surprising amount of public interest. 5 days are available for the vertical channel at each station used in processing (CERI operated stations as well as imported stations).

C. Efforts to Enhance Coordination Among RSN's and EHP

a. Product Coordination

We use data from all neighboring RSNs and process all recorded earthquakes in the NM and SE region. We assume operators track uptime themselves but notify them when timing or other problems suggest errors in timing or metadata.

We coordinate with SLU and NEIC by email and voice on magnitudes and moment tensors for events greater than about 3.

b. Response Coordination

We use email and telephone to coordinate response and messages with NEIC and regional partners immediately following all significant earthquakes in the NM and SE regions. For events great than 3.5 we coordinate magnitude with NEIC prior to submission to PDL. Portable instrument deployments are also coordinated with NEIC (Mineral, VA and Guy, AR were good examples).

c. Management Coordination

Managerial coordination is most commonly accomplished through the NIC though occasionally directly with the ANSS manager. Other regional RSNs are consulted on all issues brought before the NIC for vote.

4. 2018 Deferred Maintenance Supplement

A. AQMS Upgrade

The Linux/postgres version of AQMS is installed and operating at CERI. We opted to use 3 identical servers. Each system has two virtual machines: one VM acting as the AQMS real-time processing host (RT), and the other VM acting as the AQMS postprocessing host (PP). RT primary and PP active will run on one machine and RT standby and PP standby on the other. Both RT active and RT standby replicate to PP active. PP active replicates to PP standby. The third machine is for development and testing. We will run these systems in parallel with our Solaris/Oracle system and will switch production to the new system at a TBD date, most likely Jan 1, 2021.

B. ET Digital Upgrades

Stations GRBT, ETT, CCRT, and GFM in the ET network were converted from analog to digital. GRBT, ETT, and CCRT remain 3-c shortperiod though they are s-13 sensors which, when combined with a 24-bit DAS with an additional 3-c of acceleration, make excellent RSN stations. GFM was converted to a broadband and due to its remote location we used a Trillium Compact sensor.

5. 2019 Deferred Maintenance Supplement

Note on 2019 Deferred Maintenance which closed June 30, 2020. Hardware arrived in March 2020 and due to covid19, progress is slow on the installations. We're still waiting on cables for the broadband sensors which are due to arrive later in July, 2020. We can then begin those upgrades. We expect to have all 2019 DM upgrades completed by early fall, assuming no additional travel restrictions. As mentioned in the following section, all hardware except cables are in house and no additional funding is required to complete this work.

A. Replace CMG5TD

Equipment and ancillary hardware were obtained to replace remaining ANSS funded CMG5TD accelerographs (Figure 6). These were installed in the initial years of the ANSS to expand urban monitoring and the availability of engineering strongmotion data. Of the twenty-two operated by CERI, eleven remained to be upgraded and these funds accomplish that.

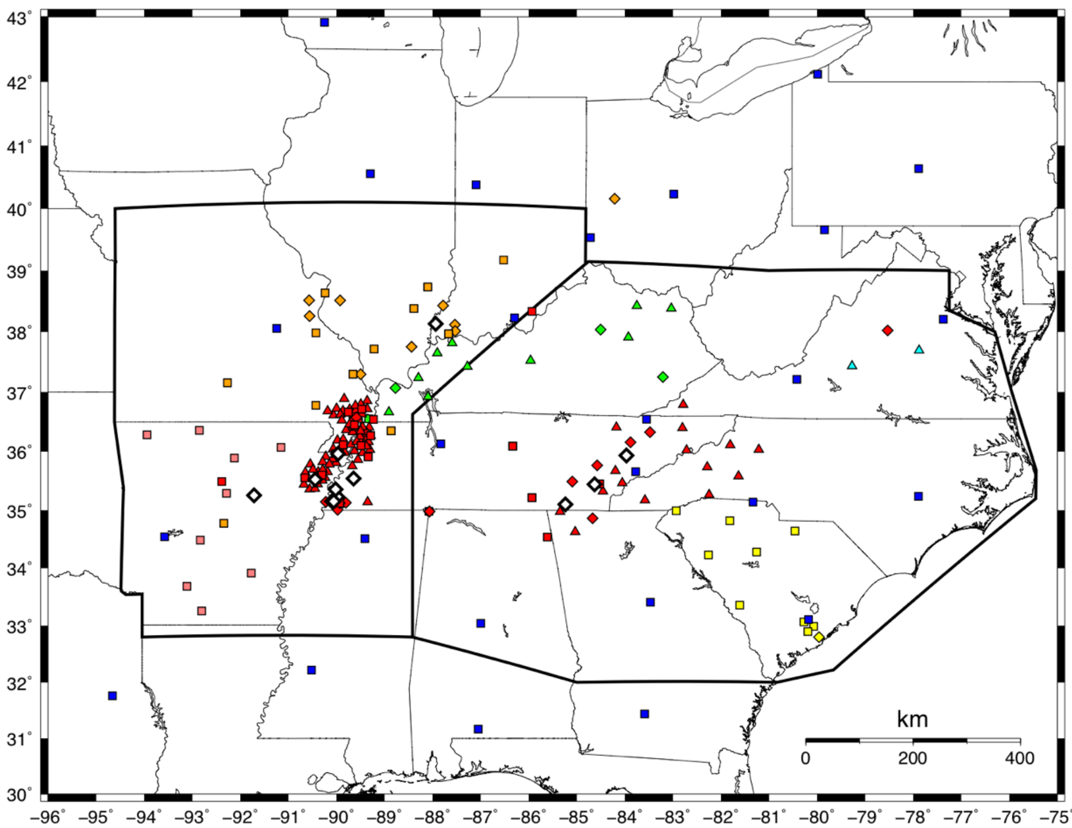

Figure 6 Map showing stations within the NM and SE polygons with CERI operated stations in red. The CMG5TD's at the eleven white diamonds with black outline are the upgrade sites. Colors denote operator (Orange St Louis U, Green Univ. of KY, Lt Blue VA Tech, Yellow Univ of South Carolina, Blue USGS). Shape denotes sensor type (square broadband, diamond strongmotion, triangle short period).

<u>B. Replace RT130 Dataloggers in NM</u>

Equipment and ancillary hardware were obtained to replace the thirteen remaining ANSS funded RT130 dataloggers in the CERI component of the NM network (Figure 7).

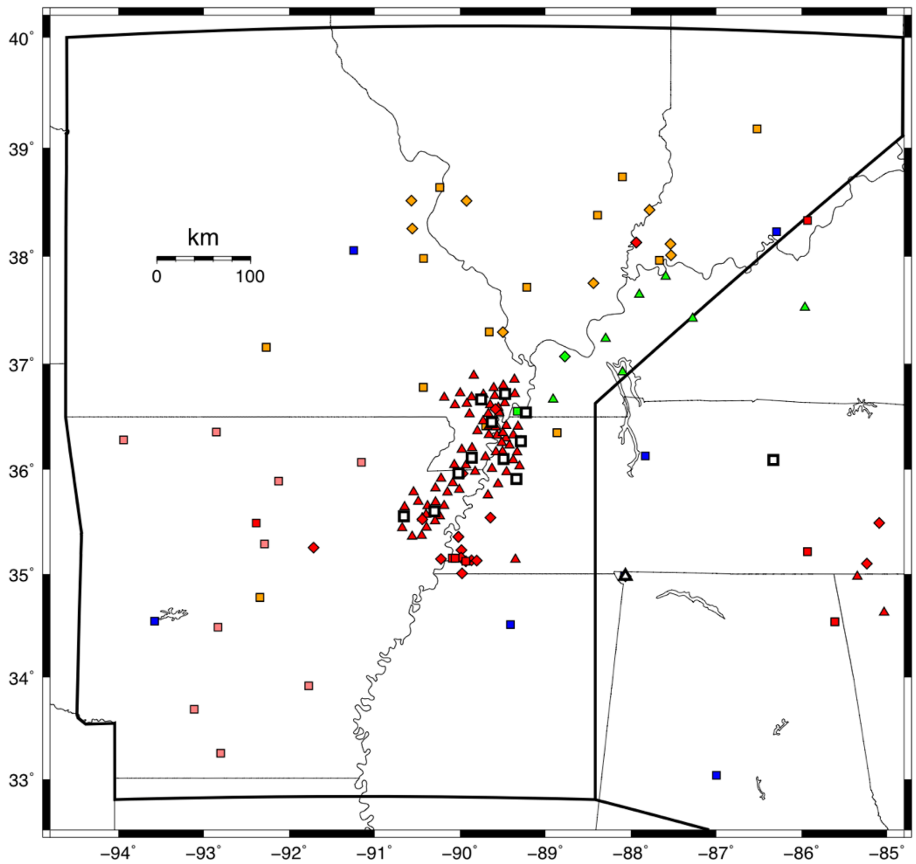

Figure 7 Map of stations in the NM polygon. The thirteen white squares with black outlines are the upgrade sites.

C. Replace RT130 Dataloggers in ET

Equipment and ancillary hardware were obtained to replace the ten remaining ANSS funded RT130 dataloggers in the CERI component of the ET network (Figure 8). Four of those ten required significant power and telemetry upgrades.

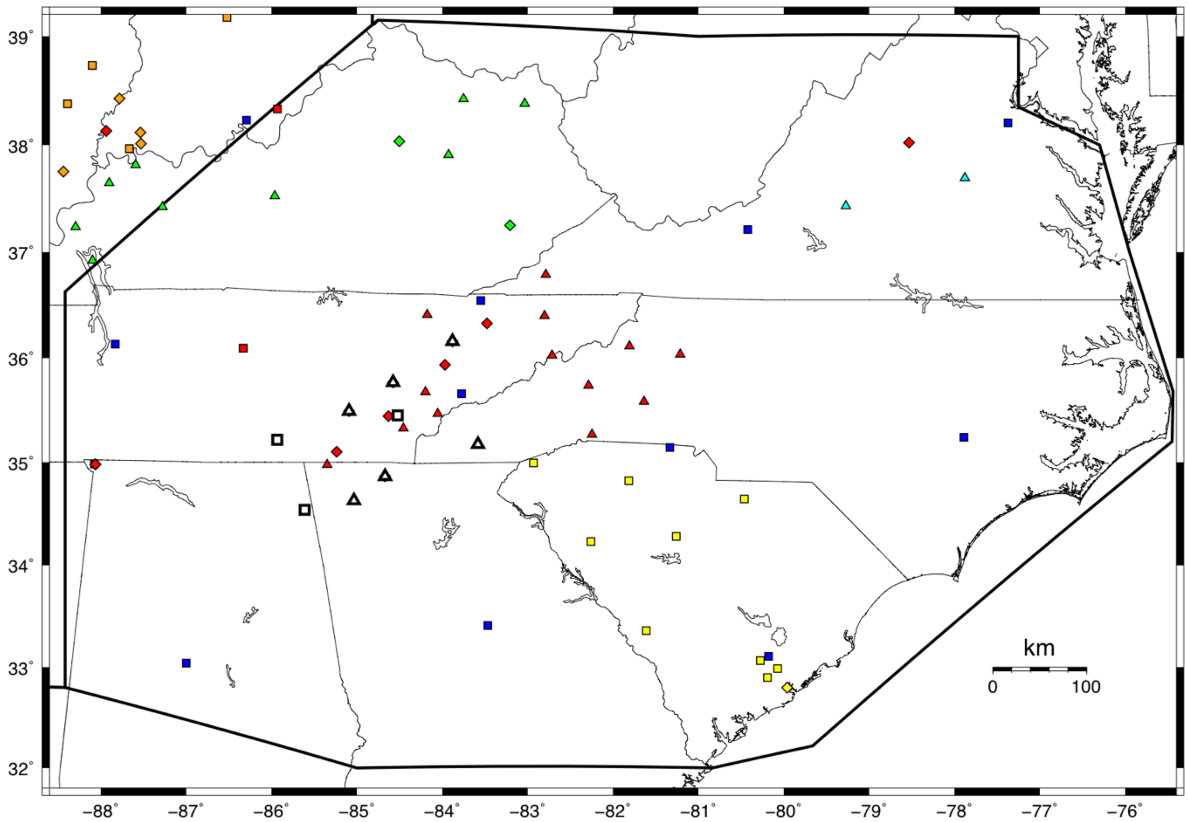

Figure 8 Map of ETSZ stations. The nine triangles and squares with black outlines have RT130 dataloggers that will be replaced with Centaur dataloggers.

D. Replace RT147 Accelerometers

Equipment and ancillary hardware were obtained to replace the fifteen remaining ANSS funded RT147 accelerometers (Figure 9).

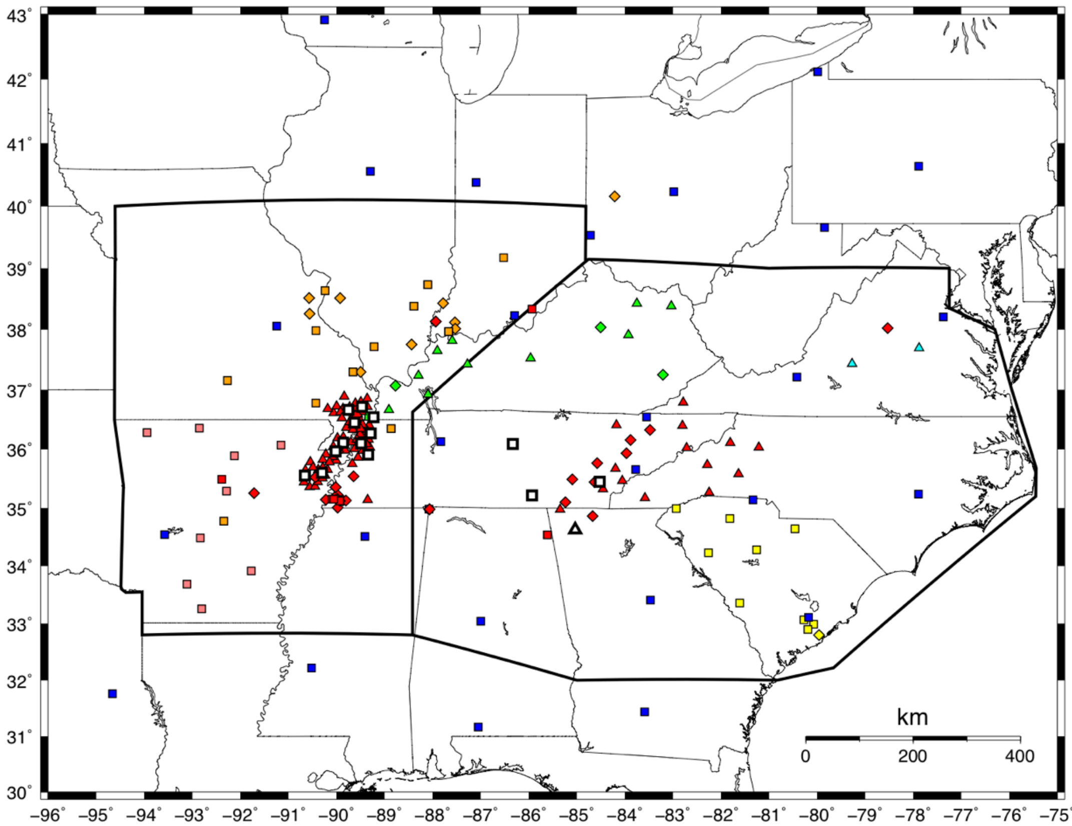

Figure 9 Map of stations in both NM and ET showing fifteen 6-c stations with white symbols and black outline that are the accelerometer upgrade sites.

E. IT Replacements and Upgrades

Two supermicro servers were acquired to replace aging systems hosting earthworm waveservers. The hardware was composed of 2 x Xeon processors (E5-2650, 12cores each), 128GB memory, 8x2TB hard drives, plus 2 64 GB SATA DOMs. We also expanded our permanent archive space from 2TB to 8TB. This space is integrated with CERI general systems and includes daily backups to a different building. Both the primary and backup capability was upgraded.

Appendix A. Station List.

In the following required station list, types are broadband (bb), strongmotion (sm), shortperiod analog (sp), and shortperiod digital (sd). All stations are three or more components. The Arkansas Geological Survey (AGS) stations are operated and maintained by CERI under a separate contract with AGS.

Table 2. Table of seismic stations operated by CERI. Broadband bb, strongmotion sm, shortperiod digital sp, and shortperiod analog sp.

Station	Net	Lat	Lon	Org	Type	hardware
CCAR	AG	33.917	-91.772	AGS	bb, sm	Reftek/Trillium 120P/RT147
FCAR	AG	35.89	-92.124	AGS	bb, sm	Reftek/Trillium 120P/RT147
HHAR	AG	36.282	-93.94	AGS	bb, sm	Reftek/Trillium 120P/RT147

Station	Net	Lat	Lon	Org	Type	hardware
LCAR	AG	36.07	-91.154	AGS	bb, sm	Reftek/Trillium 120P/RT147
WHAR	AG	35.29	-92.289	AGS	bb, sm	Reftek/Trillium 120P/RT147
WLAR	AG	33.688	-93.112	AGS	bb, sm	Reftek/Trillium 120P/RT147
X40A	AG	34.4873	-92.8342	AGS	bb, sm	Reftek/Trillium 120P/RT147
Z41A	AG	33.2577	-92.803	AGS	bb, sm	Reftek/STS2.5
U40A	AG	36.3563	-92.8535	AGS	bb,sm	Reftek/STS-2/RT147
CPCT	ET	35.45	-84.522	CERI	bb, sm	Reftek/Trillium 120P/RT147
FPAL	ET	34.54	-85.611	CERI	bb, sm	Reftek/Trillium 120P/Episensor
SWET	ET	35.216	-85.932	CERI	bb, sm	Reftek/Trillium 120P/RT147
ASTN	ET	36.327	-83.476	CERI	sd,sm	Reftek/3-c S-13/Episensor
BCRT	ET	35.766	-84.576	CERI	sd,sm	Reftek/3-c S-13/RT147
CCRT	ET	35.466	-84.053	CERI	sd,sm	Reftek/3-c S-13/Episensor
CPRT	ET	36.1567	-83.8807	CERI	sd,sm	Reftek/3-c S-13/Episensor
DYTN	ET	35.491	-85.092	CERI	sd,sm	Reftek/3-c S-13/RT147
GMG	ET	34.863	-84.67	CERI	sd,sm	Reftek/3-c S-13/Episensor
CCNC	ET	36.023	-82.714	CERI	sp	3-c S-13
CMGA	ET	34.629	-85.034	CERI	sd, sm	Reftek/3-c S-13/RT147
DSNC	ET	35.5830	-81.6361	CERI	sp	3-c S-13
ETT	ET	35.326	-84.455	CERI	sd, sm	Reftek/3-c S-13/RT147
GFM	ET	36.111	-81.807	CERI	bb, sm	L4-3D
GRBT	ET	35.674	-84.197	CERI	sd, sm	Reftek/3-c S-13/RT147
LRVA	ET	36.788	-82.786	CERI	sp	3-c S-13
MGNC	ET	35.737	-82.286	CERI	sp	3-c S-13
RCGA	ET	34.976	-85.348	CERI	sd, sm	Reftek/3-c S-13/RT147
TRYN	ET	35.267	-82.246	CERI	sp	3-c S-13
TVNC2	ET	36.0330	-81.2128	CERI	sp	3-c S-13
VHTN	ET	36.399	-82.802	CERI	sp	3-c S-13
WMTN2	ET	36.4095	-84.1755	CERI	sp	3-c S-13
WSNC	ET	35.173	-83.581	CERI	sd, sm	Reftek/3-c S-13/RT147
CLTN	NM	36.0911	-86.3315	CERI	bb, sm	Reftek/Trillium 120P/Titan
GLAT	NM	36.269	-89.288	CERI	bb, sm	Reftek/Trillium 120P/RT147
GNAR	NM	35.965	-90.018	CERI	bb, sm	Reftek/Trillium 120P/RT147
HALT	NM	35.911	-89.34	CERI	bb, sm	Reftek/Trillium 120P/RT147
HBAR	NM	35.555	-90.657	CERI	bb, sm	Reftek/Trillium 120P/RT147
HDAR2	NM	35.154	-90.089	CERI	bb, sm	CMG6TD/CMG5TD
HDBT	NM	35.153	-90.058	CERI	bb, sm	CMG6TD/CMG5TD
HENM	NM	36.716	-89.472	CERI	bb, sm	Reftek/Trillium 120P/RT147
HICK	NM	36.541	-89.229	CERI	bb, sm	Reftek/Trillium 120P/RT147
LNXT	NM	36.101	-89.491	CERI	bb, sm	Reftek/Trillium 120P/RT147/Basalt
LPAR	NM	35.602	-90.3	CERI	bb, sm	Reftek/Trillium 120P/RT147
PARM	NM	36.664	-89.752	CERI	bb, sm	Reftek/Trillium 120P/RT147
PEBM	NM	36.113	-89.862	CERI	bb, sm	Reftek/Trillium 120P/RT147
PENM	NM	36.45	-89.628	CERI	bb, sm	Reftek/Trillium 120P/RT147
PWLA	NM	34.98	-88.064	CERI	sd,sm	Reftek/3-c S-13/Episensor
ATTN	NM	35.4433	-84.6301	CERI	sm	CMG5TD
CBHS	NM	35.1326	-89.8652	CERI	sm	CMG5TD
CSTN	NM	35.101	-85.2365	CERI	sm	CMG5TD
CUET	NM	35.007	-89.976	CERI	sm	CMG5TD
CVTN	NM	35.542	-89.644	CERI	sm	CMG5TD
CVVA	NM	38.022	-78.532	CERI	sm	CMG5TD
GILT	NM	35.231	-89.983	CERI	sm	CMG5TD
GSAR	NM	35.962	-89.969	CERI	sm	CMG5TD

Station	Net	Lat	Lon	Org	Type	hardware
MCAR	NM	35.145	-90.223	CERI	sm	CMG5TD
MKAR	NM	35.526	-90.442	CERI	sm	CMG5TD
NAIT	NM	35.13	-89.804	CERI	sm	CMG5TD
NMEM	NM	36.574	-89.585	CERI	sm	CMG5TD
RDST2	NM	35.1582	-89.9872	CERI	sm	Basalt/Episensor
SEAR	NM	35.255	-91.715	CERI	sm	CMG5TD
SHTN	NM	35.933	-83.9672	CERI	sm	CMG5TD
TUMT	NM	35.123	-89.932	CERI	sm	CMG5TD
NHIN	NM	38.13	-87.936	CERI	sm, sp	CMG5TD/unknown analog
SFTN	NM	35.358	-90.019	CERI	sm, sp	CMG5TD, 3-c L28
ARPT	NM	35.756	-89.673	CERI	sp	3-c L28
BACM	NM	36.724	-89.865	CERI	sp	3-c L28
BETM	NM	36.612	-90.059	CERI	sp	3-c L28
BFAR	NM	35.873	-90.084	CERI	sp	3-c L28
BLAR	NM	35.369	-90.449	CERI	sp	3-c L28
BOAR	NM	35.823	-90.287	CERI	sp	3-c L28
BRGM	NM	36.205	-89.859	CERI	sp	3-c L28
BRNM	NM	36.724	-89.998	CERI	sp	3-c L28
BROM	NM	36.682	-90.184	CERI	sp	3-c L28
BVAR	NM	35.443	-90.677	CERI	sp	3-c L28
CACT	NM	36.2302	-89.4204	CERI	sp	3-c L28
CATM	NM	36.613	-89.647	CERI	sp	3-c L28
CHNM	NM	36.042	-89.929	CERI	sp	3-c L28
CHRM	NM	36.852	-89.362	CERI	sp	3-c L28
COKM	NM	36.711	-89.726	CERI	sp	3-c L28
CPAR	NM	35.556	-90.236	CERI	sp	3-c L28
CWPT	NM	36.009	-89.626	CERI	sp	3-c L28
DLAR	NM	35.81	-90.008	CERI	sp	3-c L28
DWDM	NM	36.796	-89.493	CERI	sp	3-c L28
EBZ	NM	35.141	-89.351	CERI	sp	3-c L28
EDIT	NM	35.863	-89.554	CERI	sp	3-c L28
EPRM	NM	36.717	-89.358	CERI	sp	3-c L28
FLPT	NM	36.409	-89.321	CERI	sp	3-c L28
FPST	NM	35.978	-89.455	CERI	sp	3-c L28
GLST	NM	36.269	-89.288	CERI	sp	3-c L28
GOBM	NM	36.191	-89.979	CERI	sp	3-c L28
GUAM	NM	36.889	-89.839	CERI	sp	3-c L28
HCAR	NM	35.6538	-90.3801	CERI	sp	3-c L28
HOPT	NM	36.327	-89.3757	CERI	sp	3-c L28
HOVM	NM	36.045	-90.067	CERI	sp	3-c L28
HTAR	NM	35.655	-90.185	CERI	sp	3-c L28
KEWM	NM	36.698	-89.593	CERI	sp	3-c L28
LFRT	NM	36.165	-89.331	CERI	sp	3-c L28
LRAR	NM	35.571	-90.398	CERI	sp	3-c L28
LVAR	NM	35.915	-90.222	CERI	sp	3-c L28
MADT	NM	36.2978	-89.4625	CERI	sp	3-c L28
MARM	NM	36.53	-89.669	CERI	sp	3-c L28
MATM	NM	36.774	-89.605	CERI	sp	3-c L28
MCAM	NM	36.12	-89.702	CERI	sp	3-c L28
MFRT	NM	36.09	-89.377	CERI	sp	3-c L28
MIST	NM	36.171	-89.502	CERI	sp	3-c L28
MLDM	NM	36.625	-89.92	CERI	sp	3-c L28

Station	Net	Lat	Lon	Org	Type	hardware
MORT2	NM	36.3245	-89.5667	CERI	sp	3-c L28
MSAR	NM	35.784	-90.147	CERI	sp	3-c L28
MTAR	NM	35.538	-90.442	CERI	sp	3-c L28
NFAR	NM	35.448	-90.393	CERI	sp	3-c L28
NHAR	NM	35.786	-90.544	CERI	sp	3-c L28
NMDM	NM	36.588	-89.552	CERI	sp	3-c L28
NNAR	NM	35.981	-89.823	CERI	sp	3-c L28
NWCT	NM	36.416	-89.459	CERI	sp	3-c L28
PGVM	NM	36.46	-89.729	CERI	sp	3-c L28
POBM	NM	36.409	-89.662	CERI	sp	3-c L28
PPLM	NM	36.403	-89.583	CERI	sp	3-c L28
QUAR	NM	35.644	-90.649	CERI	sp	3-c L28
RDGT	NM	36.256	-89.511	CERI	sp	3-c L28
RELT	NM	36.033	-89.303	CERI	sp	3-c L28
RVAR	NM	35.69	-90.286	CERI	sp	3-c L28
SJBM	NM	36.631	-89.476	CERI	sp	3-c L28
STAM	NM	36.331	-89.661	CERI	sp	3-c L28
TMAR	NM	35.695	-90.489	CERI	sp	3-c L28
TNMT	NM	36.166	-89.579	CERI	sp	3-c L28
TOPM	NM	36.526	-89.889	CERI	sp	3-c L28
TWAR	NM	35.361	-90.56	CERI	sp	3-c L28
TYAR	NM	35.509	-90.292	CERI	sp	3-c L28
WADM	NM	36.366	-89.796	CERI	sp	3-c L28
WALK	NM	36.539	-89.542	CERI	sp	3-c L28
WYBT	NM	36.348	-89.498	CERI	sp	3-c L28

Not included in this list are the 96 channels of the instrumented, base-isolated, I-40 Bridge over the Mississippi river. Hardware for all channels are episensors with granite 24-bit granite digitizers. All bridge instrumentation channels are publicly accessible via an earthworm waveserver at 141.225.169.20:16023.